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Standard Specification for

KINEMATIC GLASS VISCOMETERS[1]

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ASTM Designation: D 2515 – 66

This Standard of the American Society for Testing and Materials is issued under the fixed designation D 2515; the final number indicates the year of original adoption as standard or, in the case of revision, the year of last revision.

Scope

1. This specification covers glass capillary kinematic viscometers of all types described in detail in Appendixes A, B, and C as follows:

Type	Appendix
Modified Ostwald Viscometers	A
Suspended-Level Viscometers	B
Reverse-Flow Viscometers	C

NOTE—This specification covers viscometers suitable for use in ASTM Method D 445, Test for Viscosity of Transparent and Opaque Liquids (Kinematic and Dynamic Viscosities).[2]

Materials and Manufacture

2. (*a*) Fully annealed, low-expansion borosilicate glass shall be used for all viscometers. The size number, serial number, and manufacturer's designation shall be permanently marked on each viscometer. All timing marks shall be etched and filled with an opaque color, or otherwise made a permanent part of the viscometer.

(*b*) With the exception of the Fitz-Simons and Atlantic viscometers, all viscometers are designed to fit through a 51-mm hole in the lid of a constant-temperature bath having a liquid depth of at least 280 mm; it is assumed that the surface of the liquid will be not more than 45 mm from the top of the bath lid. For certain constant-temperature baths especially at low or high temperatures, it may be necessary to construct the viscometers with the uppermost tubes longer than shown to ensure adequate immersion in the constant-temperature bath; viscometers so modified can be used to measure viscosity within the precision of the test method. The lengths of tubes and bulbs on the figures should be held within ±10 per cent or ±10 mm, whichever is less.

Nomenclature for Figures

3. The more frequently used letters on the figures in the appendixes are as follows:

A	Lower reservoir
B	Suspended level bulb
C and *J*	Timing bulbs
D	Upper reservoir
E, *F*, and *I*	Timing marks
G and *H*	Filling marks

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[1] Under the standardization procedure of the Society, this specification is under the jurisdiction of the ASTM Committee D-2 on Petroleum Products and Lubricants. A list of members may be found in the ASTM Year Book.

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[2] Appears in this publication.

K	Overflow tube
L	Mounting tube
M	Lower vent tube
N	Upper vent tube
P	Connecting tube
R	Working capillary

Viscometer Holder and Alignment

4. (*a*) All viscometers shall be mounted in a constant-temperature bath with tube L held within 1 deg of the vertical as observed with a plumb bob or other equally accurate inspection means. A number of commercially available holders are so designed that tube L is held perpendicular to the lid of the constant-temperature bath, thus requiring that the lid be within 1 deg of the horizontal.

(*b*) Round metal tops, designed to fit above a 51-mm hole in the lid of the bath, are frequently cemented onto the Zeitfuchs, Zeitfuchs Cross-Arm, and Lantz-Zeitfuchs viscometers which then are permanently mounted onto the lid of the bath; a rectangular metal top, 25 by 59 mm, is often cemented onto the Zeitfuchs Cross-Arm and Zeitfuchs viscometers.

(*c*) In each figure, the numbers which follow the tube designation indicate the outside tube diameter in millimeters. It is important to adhere to these diameters and the designated spacing to ensure that holders will be interchangeable.

Viscosity Calculation[3]

5. (*a*) *Kinematic Viscosity*, expressed in centistokes (cSt), is calculated as follows:

$$\text{Kinematic viscosity, cSt} = Ct \quad \ldots\ldots (1)$$

where:

C = calibration constant, cSt/sec, and
t = flow time, sec.

(*b*) *Kinetic Energy Correction*—A more general form of Eq 1 is as follows:

$$\text{Kinematic viscosity, cSt} = Ct - E/t^2 \quad \ldots (2)$$

where:

E = kinetic energy factor, cSt-sec^2. While E is not a constant, it can be approximated by the following equation:

$$E = \frac{1.66\ V^{3/2}}{L(CD)^{1/2}} \quad \ldots\ldots\ldots\ldots (3)$$

where:

V = volume of timing bulb, cm^3,
L = working capillary length, cm, and
D = working capillary diameter, cm.

(*1*) The viscometers described in Appendixes A, B, and C are designed such that the kinetic energy correction term, E/t^2, is negligible if the flow time is more than 200 sec, with the exception of several sizes for the measurement of low-viscosity liquids as noted in the tables of dimensions of viscometers.

(*2*) The viscosity ranges shown in these tables are based upon a minimum flow time of 200 sec and a maximum flow time of 1000 sec. For viscometers whose constants are 0.05 cSt/sec or less, a kinetic energy correction may be significant if the minimum 200-sec flow time is not observed; the maximum flow time of 1000 sec is arbitrarily set for convenience. The precision section of Method D 445 is based on a 200-sec minimum flow time. Where the minimum flow time exceeds 200 sec, a note appears in the appropriate table.

(*c*) *Surface Tension Correction*—If the two menisci have different average diameters during the flow time and if the surface tension of the sample differs substantially from the calibrating liquid, a surface tension correction is necessary. The change in the C constant is given approximately as follows:

$$C_2 = C_1\left[1 + \frac{2}{gh}\left(\frac{1}{r_u} - \frac{1}{r_1}\right)\left(\frac{\gamma_1}{\rho_1} - \frac{\gamma_2}{\rho_2}\right)\right] \quad \ldots (4)$$

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[3] M. R. Cannon, "Derivation of Viscosity Equation and Sources of Error in Viscometry," Private Report to ASTM Subcommittee on Viscosity, February, 1950. M. R. Cannon and R. E. Manning, "Viscosity Measurement, The Kinetic Energy Correction." Copies available free of charge from Cannon Instrument Co., P. O. Box 16, State College, Pa. 16801.

where:

g = acceleration of gravity, cm/sec^2,
h = average driving head, cm,
r_u = average radius of the upper meniscus, cm,
r_l = average radius of the lower meniscus, cm,
γ = surface tension, dynes/cm,
ρ = density, g/cm^3, and
1, 2 subscripts = calibration liquid and test sample, respectively.

While this correction applies to all viscometers, a number of viscometers are designed to minimize the surface tension correction. The greatest correction normally encountered is with a viscometer calibrated with water and used for oils. Generally viscometers are calibrated and used with hydrocarbons whose surface tensions are close enough so these corrections are insignificant.

(*d*) *Effect of Temperature*—The calibration constant, C, is independent of temperature for all suspended-level viscometers and those viscometers which have the volume of sample adjusted at bath temperatures.

(*1*) The following viscometers, which have a fixed volume charged at ambient temperature, have a variation in C constant with temperature: Cannon-Fenske Routine, Pinkevitch, Cannon-Manning Semi-Micro, and Cannon-Fenske Opaque.

(*2*) The following equation can be used to calculate C at temperatures other than the calibration temperature for the Cannon-Fenske Routine, Pinkevitch, and Cannon-Manning Semi-Micro viscometers:

$$C_2 = C_1\left[1 + \frac{4V(\rho_2 - \rho_1)}{\pi D^2 h \rho_2}\right] \ldots\ldots (5)$$

The temperature dependence of C for the Cannon-Fenske Opaque (reverse-flow) viscometer is given as follows:

$$C_2 = C_1\left[1 - \frac{4V(\rho_2 - \rho_1)}{\pi D^2 h \rho_2}\right] \ldots\ldots (6)$$

where:

V = volume of charge, cm,^{3}
D = average diameter of the meniscus in the lower reservoir for the Cannon-Fenske Routine, Pinkevitch and Cannon-Manning Semi-Micro viscometers, and in the upper reservoir of the Cannon-Fenske Opaque viscometer, cm,
h = average driving head, cm, and
1, 2 subscripts = calibration and test temperature, respectively.

APPENDIX A

MODIFIED OSTWALD VISCOMETERS

Scope

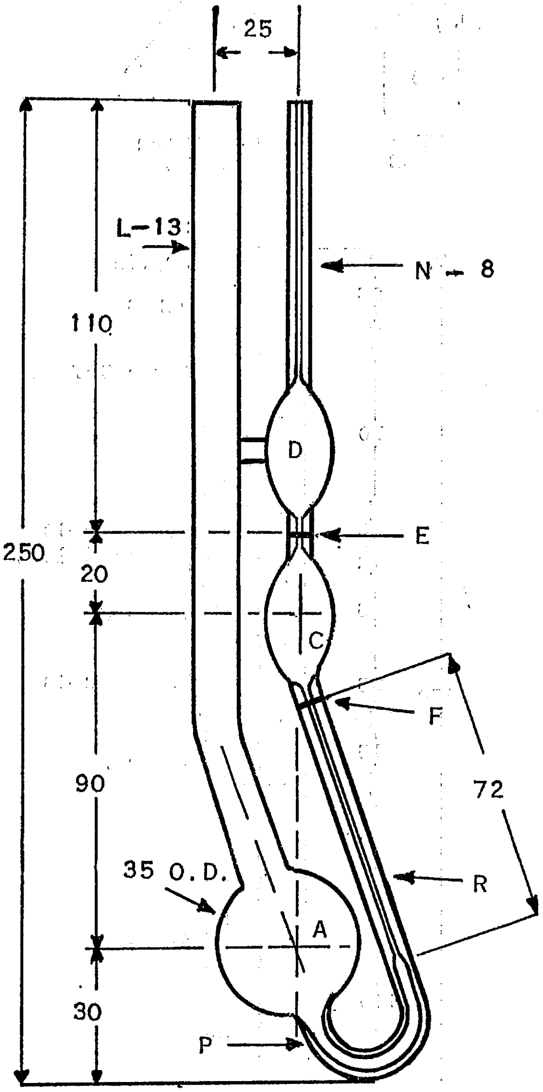
A1. The modified Ostwald viscometers for transparent liquids have the basic design of the Ostwald viscometer, but are modified as follows to ensure a constant volume of sample in the viscometer: at the filling temperature for the Cannon-Fenske Routine, Cannon-Manning Semi-Micro and Pinkevitch viscometers, and at the test temperature for the Zeitfuchs, SIL, BS/U-tube, and BS/U Miniature viscometers. These viscometers are used for the measurement of the kinematic viscosity of transparent Newtonian liquids up to 20,000 cSt.

Apparatus

A2. Detailed drawings of the modified Ostwald viscometers are shown in Figs. A1 through A7. Tables A1 through A7 give the size designation, approximate constants, kinematic viscosity range, capillary diameter, and bulb volumes for each viscometer.

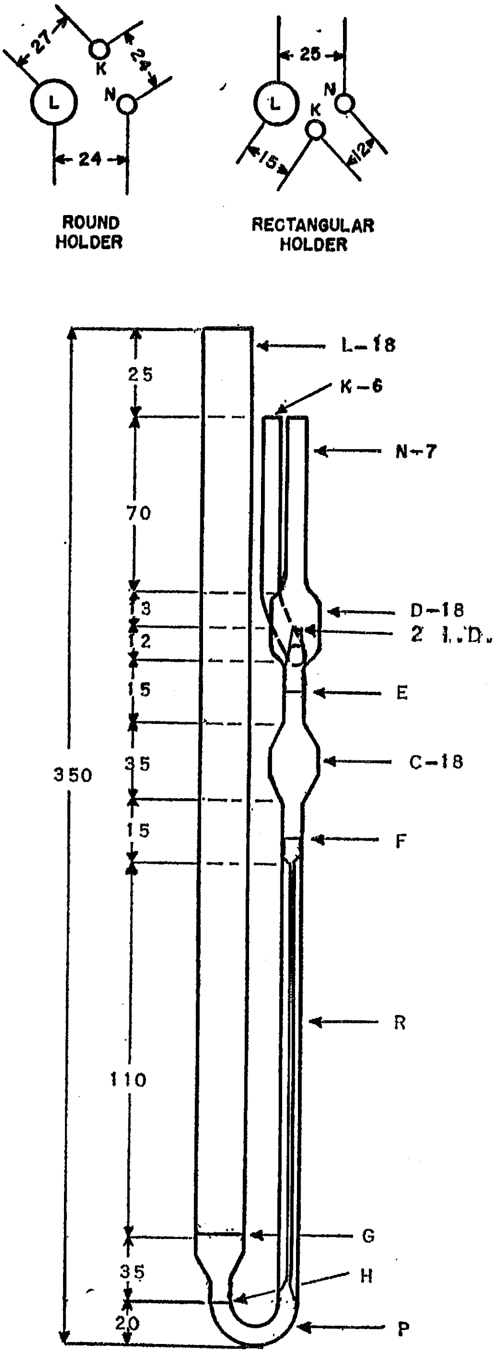
Operating Instructions

A3. A standard operating procedure applicable to all glass capillary kinematic viscometers is contained in Method D 445. Operating instructions for the modified Ostwald viscometers are



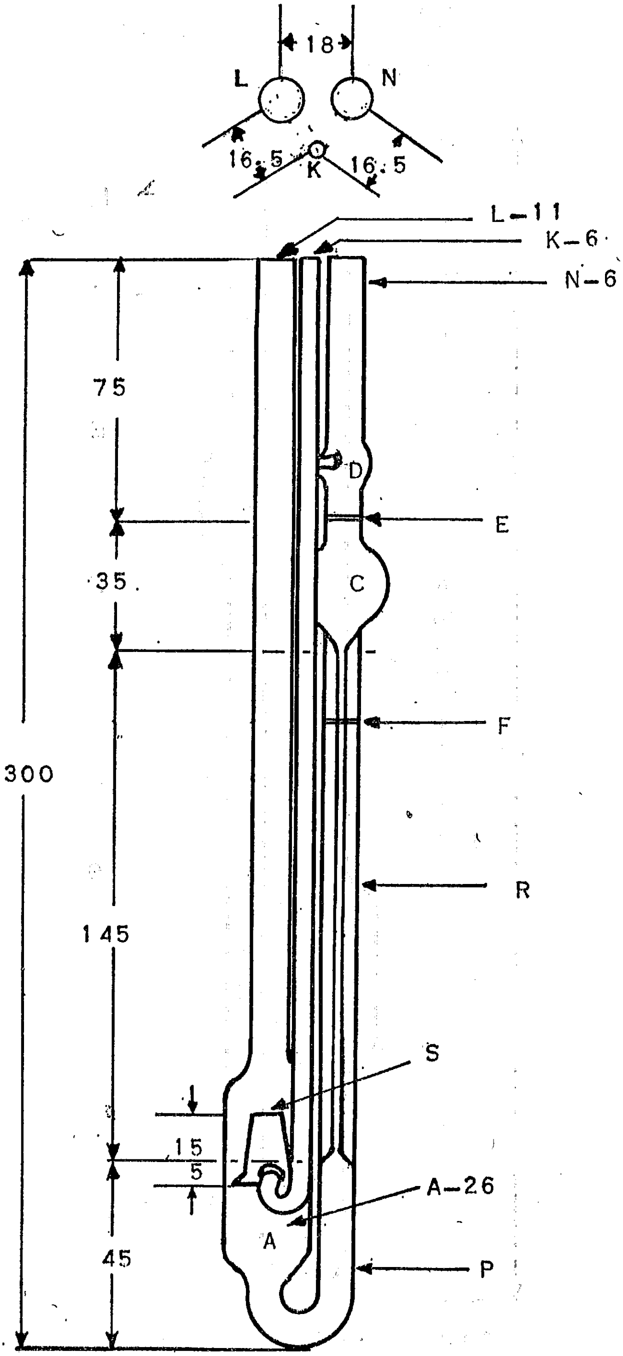
NOTE—All dimensions are in millimeters.

FIG. A1—Cannon-Fenske Routine Viscometer for Transparent Liquids.



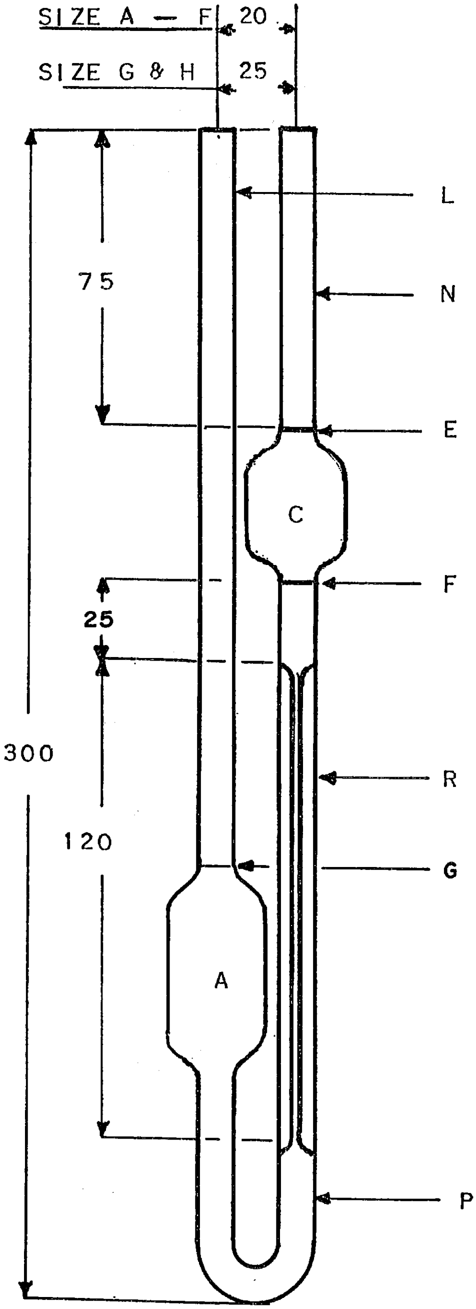
NOTE—All dimensions are in millimeters.

FIG. A2—Zeitfuchs Viscometer for Transparent Liquids.

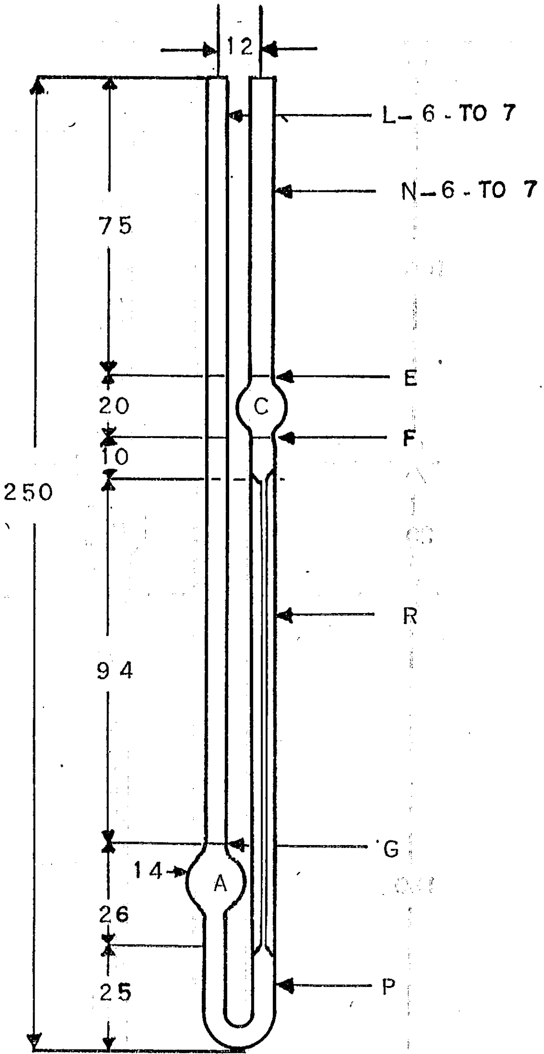


NOTE—All dimensions are in millimeters.

FIG. A3—SIL Viscometer for Transparent Liquids.

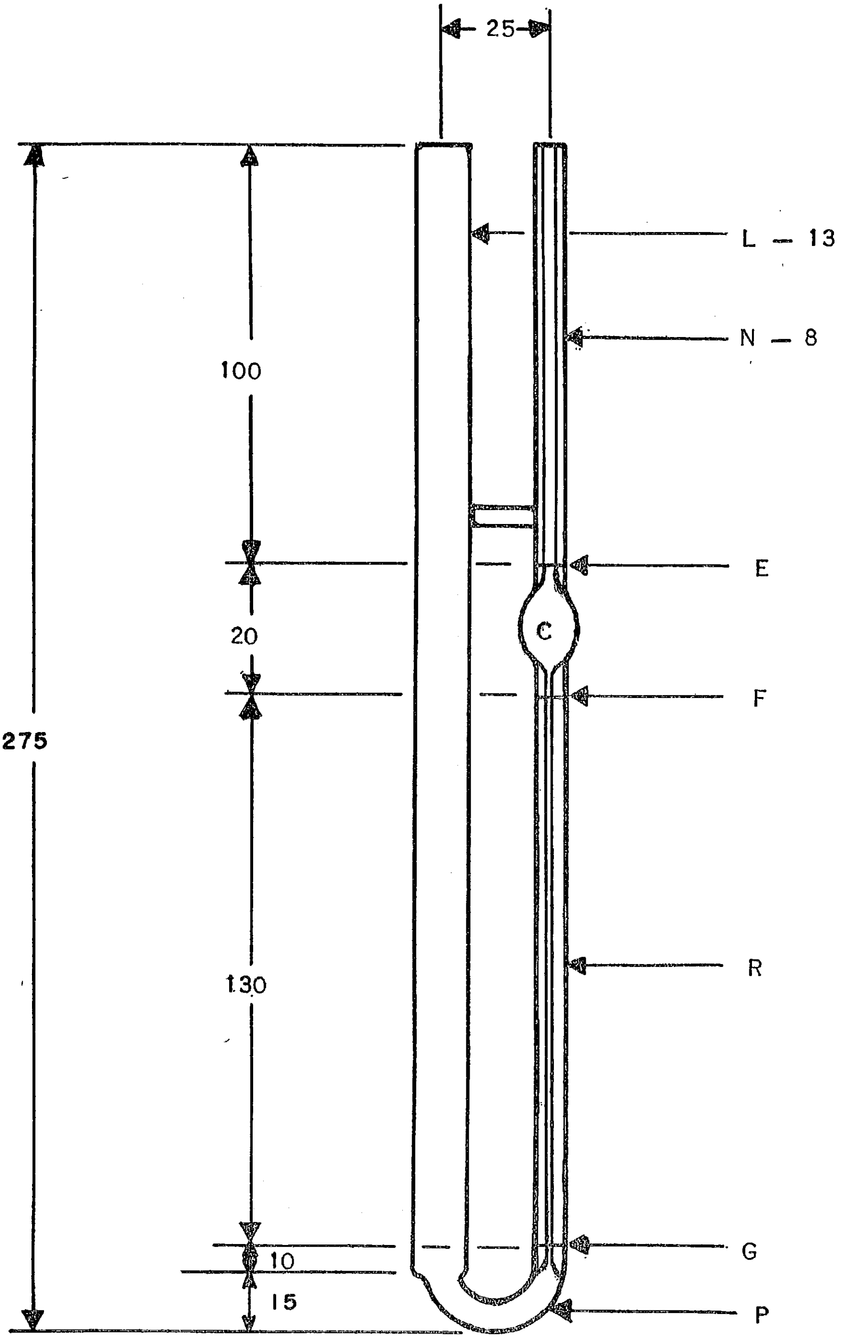


NOTE—All dimensions are in millimeters.
FIG. A4—BS/U-Tube Viscometer for Transparent Liquids.



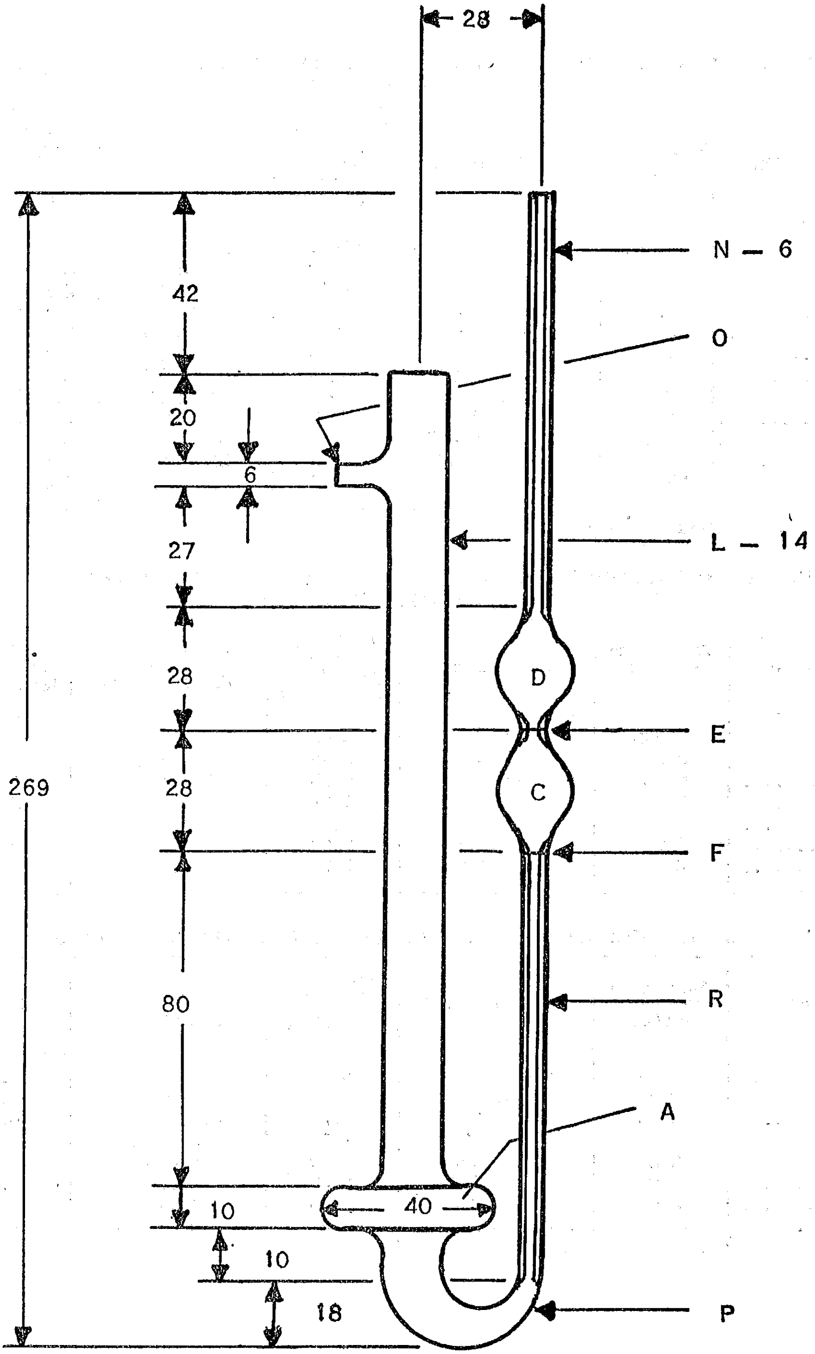
NOTE—All dimensions are in millimeters.

FIG. A5—BS/U/M Miniature Viscometer for Transparent Liquids.



NOTE—All dimensions are in millimeters.

FIG. A6—Cannon-Manning Semi-Micro Viscometer for Transparent Liquids.



Note—All dimensions are in millimeters.

Fig. A7—Pinkevitch Viscometer for Transparent Liquids.

TABLE A1—DIMENSIONS AND VISCOSITY RANGES OF CANNON-FENSKE ROUTINE VISCOMETERS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube R, mm (±2 per cent)	Inside Diameter of Tubes *N*, *E*, and *P*, mm	Bulb Volume, ml (±5 per cent)	
					D	*C*
25	0.002	0.5[a] to 2	0.30	2.6 to 3.0	3.1	1.6
50	0.004	0.8 to 4	0.44	2.6 to 3.0	3.1	3.1
75	0.008	1.6 to 8	0.54	2.6 to 3.2	3.1	3.1
100	0.015	3 to 15	0.63	2.8 to 3.6	3.1	3.1
150	0.035	7 to 35	0.78	2.8 to 3.6	3.1	3.1
200	0.1	20 to 100	1.01	2.8 to 3.6	3.1	3.1
300	0.25	50 to 250	1.27	2.8 to 3.6	3.1	3.1
350	0.5	100 to 500	1.52	3.0 to 3.8	3.1	3.1
400	1.2	240 to 1 200	1.92	3.0 to 3.8	3.1	3.1
450	2.5	500 to 2 500	2.35	3.5 to 4.2	3.1	3.1
500	8	1 600 to 8 000	3.20	3.7 to 4.2	3.1	3.1
600	20	4 000 to 20 000	4.20	4.4 to 5.0	4.3	3.1

[a] 250 sec, minimum flow time.

TABLE A2—DIMENSIONS AND VISCOSITY RANGES OF ZEITFUCHS VISCOMETER FOR TRANSPARENT LIQUIDS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Inside Diameter of Tubes *P*, *E*, and *F*, mm	Volume, Bulb *C*, ml (±5 per cent)
1	0.003	0.6 to 3	0.42	3.8 to 4.2	3.0
2	0.01	2 to 10	0.59	3.8 to 4.2	4.0
3	0.03	6 to 30	0.78	3.8 to 4.2	4.0
4	0.1	20 to 100	1.16	3.8 to 4.2	5.0
5	0.3	60 to 300	1.54	3.8 to 4.2	5.0
6	1.0	200 to 1000	2.08	3.8 to 4.2	5.0
7	3.0	600 to 3000	2.76	3.8 to 4.2	5.0

TABLE A3—DIMENSIONS AND VISCOSITY RANGES FOR SIL VISCOMETERS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Inside Diameter of Tubes *E* and *P*, mm	Volume, Bulb *C*, ml (±5 per cent)
0C	0.003	0.6 to 3	0.41	4.5 to 5.5	3.0
1	0.01	2.0 to 10	0.61	4.5 to 5.5	4.0
1C	0.03	6 to 30	0.73	4.5 to 5.5	4.0
2	0.1	20 to 100	1.14	4.5 to 5.5	5.0
2C	0.3	60 to 300	1.50	4.5 to 5.5	5.0
3	1.0	200 to 1 000	2.03	4.5 to 5.5	5.0
3C	3.0	600 to 3 000	2.68	4.5 to 5.5	5.0
4	10.0	2 000 to 10 000	3.61	4.5 to 5.5	5.0

TABLE A4—DIMENSIONS AND VISCOSITY RANGES FOR BS/U-TYPE VISCOMETERS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Outside Diameter of Tubes[a]		Volume Bulb *C*, ml (±5 per cent)	Vertical Distance, *F* to *G*	Outside Diameter of Bulbs *A* and *C*
				L and *P*, mm	*N*, mm			
A	0.003	0.9[b] to 3	0.50	8 to 9	6 to 7	5.0	91 ± 4	21 to 23
B	0.01	2.0 to 10	0.71	8 to 9	6 to 7	5.0	87 ± 4	21 to 23
C	0.03	6 to 30	0.88	8 to 9	6 to 7	5.0	83 ± 4	21 to 23
D	0.1	20 to 100	1.40	9 to 10	7 to 8	10.0	78 ± 4	25 to 27
E	0.3	60 to 300	2.00	9 to 10	7 to 8	10.0	73 ± 4	25 to 27
F	1.0	200 to 1 000	2.50	9 to 10	7 to 8	10.0	70 ± 4	25 to 27
G	3.0	600 to 3 000	4.00	10 to 11	9 to 10	20.0	60 ± 3	32 to 35
H	10.0	2 000 to 10 000	6.10	10 to 11	9 to 10	20.0	50 ± 3	32 to 35

[a] Use 1 to 1.25-mm wall tubing for *N*, *P*, and *L*.

[b] 300 sec minimum flow time.

TABLE A5—DIMENSIONS AND VISCOSITY RANGES FOR BS/U/M VISCOMETER.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Outside Diameter of Tubes *L*, *N*, and *P*[a]	Volume, Bulb *C*, ml (±5 per cent)
M1	0.001	0.2 to 1	0.20	6 to 7	0.50
M2	0.005	1 to 5	0.30	6 to 7	0.50
M3	0.015	3 to 15	0.40	6 to 7	0.50
M4	0.04	8 to 40	0.50	6 to 7	0.50
M5	0.1	20 to 100	0.65	6 to 7	0.50

[a] Use 1 to 1.25-mm wall tubing for *N*, *P*, and *L*.

TABLE A6—DIMENSIONS AND VISCOSITY RANGES FOR CANNON-MANNING SEMI-MICRO VISCOMETER.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Inside Diameter of Tubes		Volume, Bulb *C*, ml (±5 per cent)
				N and *F*, mm	*P*, mm	
25	0.002	0.4 to 2.0	0.22 ± 0.01	1.0 to 1.2	0.4 to 0.7	0.31
50	0.004	0.8 to 4	0.26 ± 0.01	1.0 to 1.2	0.5 to 0.8	0.31
75	0.008	1.6 to 8	0.31 ± 0.01	1.1 to 1.3	0.6 to 0.8	0.31
100	0.015	3 to 15	0.36 ± 0.02	1.2 to 1.4	0.7 to 0.9	0.31
150	0.035	7 to 35	0.47 ± 0.02	1.2 to 1.4	0.8 to 1.0	0.31
200	0.1	20 to 100	0.61 ± 0.02	1.4 to 1.7	0.9 to 1.2	0.31
300	0.25	50 to 250	0.76 ± 0.02	1.5 to 1.8	1.2 to 1.6	0.31
350	0.5	100 to 500	0.90 ± 0.03	1.8 to 2.2	1.5 to 1.8	0.31
400	1.2	240 to 1200	1.13 ± 0.03	2.0 to 2.4	1.6 to 2.0	0.31
450	2.5	500 to 2 500	1.40 ± 0.04	2.2 to 2.6	2.0 to 2.5	0.31
500	8	1 600 to 8 000	1.85 ± 0.05	2.4 to 2.8	2.5 to 2.8	0.31
600	20	4 000 to 20 000	2.35 ± 0.05	3.0 to 3.4	2.7 to 3.0	0.31

outlined in Paragraphs (*a*) through (*g*) with emphasis on procedures that are specific to this group of viscometers.

(*a*) Select a clean, dry calibrated viscometer which will give a flow-time greater than 200 sec or the minimum shown in the table of dimensions.

(*b*) Charge the sample into the viscometer in the manner dictated by the design of the instrument. Strain the sample if solid particles are present.

(*1*) To charge the Cannon-Fenske Routine, Cannon-Manning Semi-Micro, and Pinkevitch viscometers, invert the viscometer and apply suction to tube *L* (the Pinkevitch viscometer has a side arm *O* to which vacuum is applied, with finger on tube *L* being used to control liquid flow) with tube *N* immersed in the liquid sample. Draw the sample to timing mark *F* for the Cannon-Fenske Routine and Pinkevitch viscometers and fill-line *G* for the Cannon-Manning Semi-Micro viscometer. Mount the viscometer upright in the constant-temperature bath keeping tube *L* vertical.

TABLE A7—DIMENSIONS AND VISCOSITY RANGES FOR PINKEVITCH VISCOMETER.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Bulb Volumes, ml (±5 per cent)	
				D	*C*
0	0.0017	0.6[a] to 1.7	0.40	3.7	3.7
1	0.0085	1.7 to 8.5	0.60	3.7	3.7
2	0.027	5.4 to 27	0.80	3.7	3.7
3	0.065	13 to 65	1.00	3.7	3.7
4	0.14	28 to 140	1.20	3.7	3.7
5	0.35	70 to 350	1.50	3.7	3.7
6	1.0	200 to 1 000	2.00	3.7	3.7
7	2.6	520 to 2 600	2.50	3.7	3.7
8	5.3	1 060 to 5 300	3.00	3.7	3.7
9	9.9	1 980 to 9 900	3.50	3.7	3.7
10	17	3 400 to 17 000	4.00	3.7	3.7

[a] 350 sec minimum flow time.

(*2*) Mount the Zeitfuchs viscometer in the constant-temperature bath, keeping tube *L* vertical. Pour sample through tube *L* to fill mark *G*. Allow 15 min for the sample to attain bath temperature and become free of air bubbles. Attach the vacuum line with stopcock and trap to tube *K*. Slowly draw the sample into timing bulb *C* by partially opening the stopcock in the vacuum line and partially closing tube *N* with the finger. Allow the excess liquid to flow into bulb *D* and through tube *K* into the trap in the vacuum line. When the liquid in tube *L* reaches a point 2 to 5 mm above line *H*, hold it at this point by alternately closing and opening tube *N* to the atmosphere with the finger for the time shown below to permit the sample to drain from the walls of tube *L*.

Kinematic Viscosity of Sample, cSt	Drainage Time, sec
Under 10	10 to 20
10 to 100	40 to 60
100 to 1000	100 to 120
Over 1000	180 to 200

Adjust the working volume by drawing the lower meniscus exactly to mark *H*, making sure that the sample completely fills the viscometer between mark *H* and the tip of the overflow in bulb *D;* after this final adjustment of the working volume, remove the finger and close or remove the connection to the vacuum source. The final adjustment may be more conveniently made by disconnecting the vacuum and applying pressure to the mounting tube *L* by use of a rubber bulb.

(*3*) Charge the SIL viscometer by tilting it about 30 deg from the vertical, with bulb *A* below capillary *R*. Introduce enough of the sample into tube *L* for bulb *A* to fill completely and overflow into the gallery. Return the viscometer to the vertical position and mount it in the constant-temperature bath so that tube *L* is vertical. The quantity of sample charged should be such that the level in the lower reservoir should be 3 to 14 mm above opening *S*. The sample will rise in capillary *R* somewhat higher than opening *S*. After the temperature equilibrium has been reached, remove excess sample from the gallery by suction applied to tube *K*.

(*4*) Mount the BS/U-tube or BS/U/M Miniature viscometer in the constant-temperature bath keeping tube *L* vertical. Using a long pipet to minimize any wetting of tube L above fill mark G, fill bulb A with a slight excess of sample. After allowing the sample to attain bath temperature, adjust the volume of the sample to bring the liquid level within 0.2 mm of fill mark *G* by withdrawing the sample with a pipet.

(*c*) Allow the viscometer to remain in the constant-temperature bath a sufficient time to ensure that the sample reaches temperature equilibrium (for nonviscous liquids, about 10 min at 100 F, 15 min at 210 F, and 20 min at 275 F).

(*d*) Use vacuum (or pressure if the sample contains volatile constituents) to draw the sample through bulb *C* to about 5 mm above upper timing mark *E*. Release the vacuum, and allow the sample to flow by gravity.

(*e*) Measure, to the nearest 0.1 sec, the time required for the leading edge of the meniscus to pass from timing mark *E* to timing mark *F*. If this flow time is less than 200 sec, select a smaller capillary viscometer and repeat steps (*b*) through (*e*).

(*f*) Repeat steps (*d*) and (*e*) making a duplicate measurement of flow time. If the two measurements agree within 0.2 per cent, use the average for calculating kinematic viscosity.

(*g*) Clean the viscometer thoroughly by several rinsings with an appropriate solvent completely miscible with the sample, followed by rinsing with a completely volatile solvent. Dry the viscometer by passing a slow stream of filtered, dry air through the viscometer for 2 min, or until the last trace of solvent is removed.

REFERENCES

(1) M. R. Cannon and M. R. Fenske, "Viscosity Measurement," *Industrial and Engineering Chemistry, Analytical Edition*, Vol. 10, 1938, p. 297.

(2) E. H. Zeitfuchs, "An Accurate Viscometer for Refinery Control Laboratories," *Proceedings*, American Petroleum Institute, Vol. 20 (III), 1939.

(3) E. L. Ruh, R. W. Walker, and E. W Dean, "The SIL Viscometer," *Industrial and Engineering Chemistry*, Vol. 13, 1941, p. 346.

(4) "Method for Determining Kinematic Viscosity," *GOST 33-53* (Russian Standard). Available from the USA Standards Institute, 10 East 40th St., New York, N. Y. 10016.

(5) "Kinematic Viscosity of Oil," *CSN 65-6216* (Czech Standard). Available from the USA Standards Institute, 10 East 40th St., New York, N. Y. 10016.

APPENDIX B

SUSPENDED LEVEL VISCOMETERS

Scope

B1. The suspended-level viscometers include the Ubbelohde, FitzSimons, Atlantic, BS/IP/SL, BS/IP/SL(S), BS/IP/MSL, Cannon-Ubbelohde, and Cannon-Ubbelohde Semi-Micro designs. They are distinguished by the lower meniscus being "suspended" immediately below the working capillary. This suspension ensures a uniform driving head of liquid independent of the quantity of sample charged into the viscometer, and thus the viscometer constant is independent of temperature. By making the diameter of the lower meniscus approximately equal to the average diameter of the upper meniscus, the "surface tension" correction is greatly reduced. Suspended-level viscometers are used for the measurement of the kinematic viscosities of transparent, Newtonian liquids up to 100,000 cSt.

Apparatus

B2. Detailed drawings of the suspended-level viscometers for transparent liquids are shown in Figs. B1 through B8. Tables B1 through B8 give the size designations, approximate constants, viscosity range, capillary diameter, and bulb volumes for each viscometer.

Operating Instructions

B3. A standard operating procedure, applicable to all glass, capillary, kinematic viscometers is contained in Method D 445. Operating instructions for the suspended-level types are outlined in Paragraphs (*a*) through (*g*) with emphasis on procedures that are specific to this group of viscometers.

(*a*) Select a clean, dry viscometer which will give a flow time greater than 200 sec or the minimum shown in the table of dimensions.

(*b*) Charge the sample into the viscometer in the manner dictated by the design of the instrument. Filter the sample if solid particles are present.

(*1*) Charge the Ubbelohde and Cannon-Ubbelohde viscometers by tilting the instrument about 30 deg from the vertical and pouring sufficient sample through tube *L* into bulb *A* so that when the viscometer is returned to the vertical the meniscus is between fill marks *G* and *H*, and tube *P* completely fills without entraping air. Mount the viscometer in the constant-temperature bath keeping tube *L* vertical.

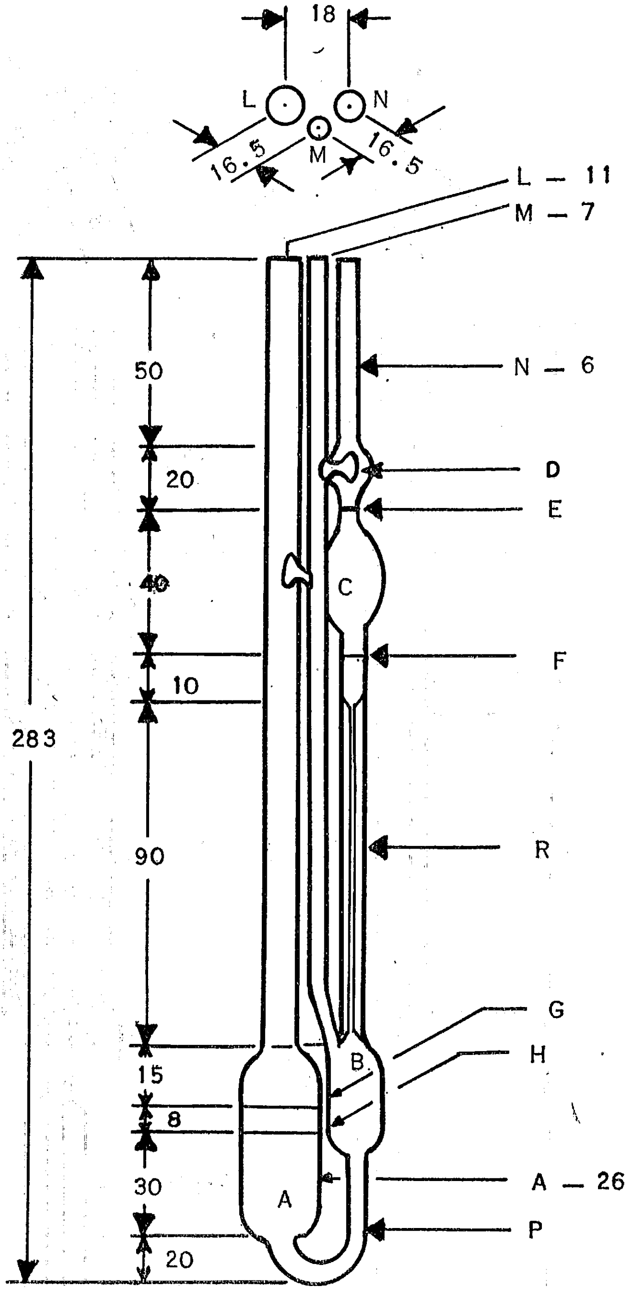
To facilitate charging very viscous liquids, the viscometer may be inverted with tube *L* placed in the sample. Apply vacuum to tube *N*, closing tube *M* by a finger or rubber stopper; draw sufficient sample into tube *L* such that after wiping *L* clean and placing the viscometer in the constant-temperature bath, bulb *A* will fill as described above.

(*2*) Charge the BS/IP/SL, BS/IP/SL(S), BS/IP/MSL, and FitzSimons viscometers through tube *L* with sufficient sample to fill bulb *A*, but not bulb *B*. The viscometer may be mounted vertically in the constant-temperature bath either prior to or following charge of the sample into the viscometer.

(*3*) Permanently mount the Atlantic viscometer in the constant-temperature bath with the enlargement *S* resting on the top-split collar, and the lower end of capillary tube *R*, 25 mm from the bottom of the bath. Pour the sample into a clean 50-ml beaker. Charge the viscometer by positioning the beaker and sample under tube *L* so that it will be completely immersed in the sample. Slowly apply vacuum to tube *N* by turning the three-way stopcock *O* to vacuum. Draw the sample into the viscometer filling capillary *R*, timing bulb *C*, and partially filling upper bulb *D*. Close stopcock *O* holding the sample in the viscometer. If only a small sample is available, a short length of rubber tipped glass tubing can be placed in the beaker with the rubber against the bottom of capillary tube *R*, and the sample drawn up as above.

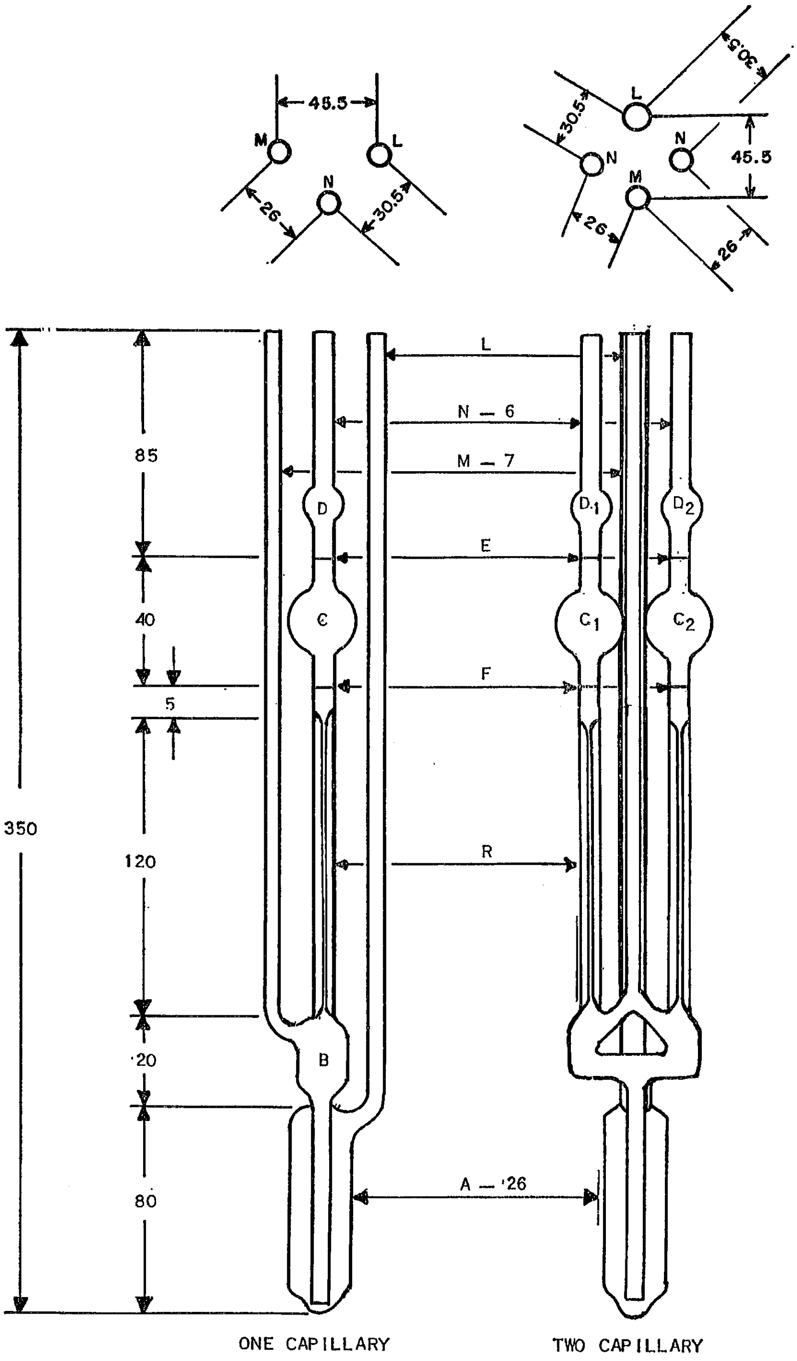
(*c*) Allow the viscometer to remain in the constant-temperature bath a sufficient time to ensure that the sample reaches temperature equilibrium (for nonviscous liquids about 10 min at 100 F, 15 min at 210 F, and 20 min at 275 F; viscous liquids may require double this time).

(*d*) Except for the Atlantic viscometer which already has the sample in position, close tube *M* with the finger and use vacuum (or pressure,



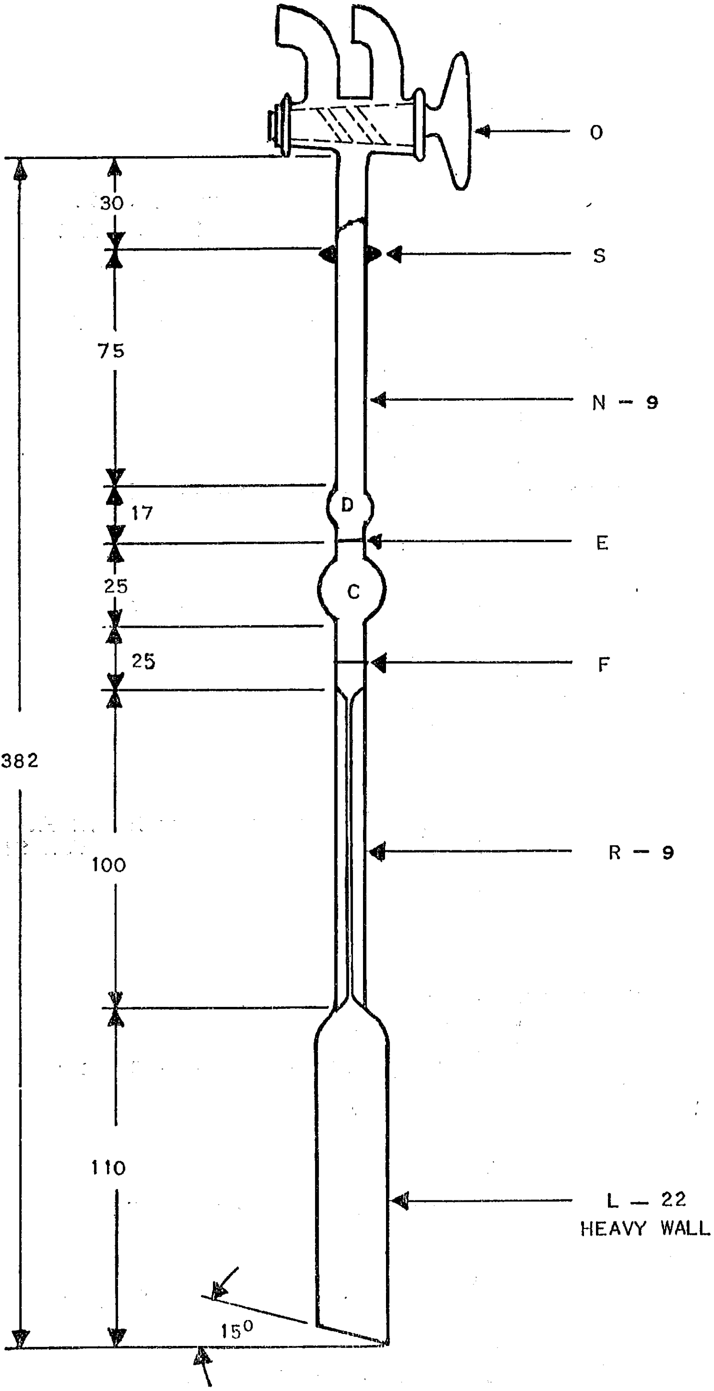
NOTE—All dimensions are in millimeters.

FIG. B1—Ubbelohde Viscometer for Transparent Liquids.



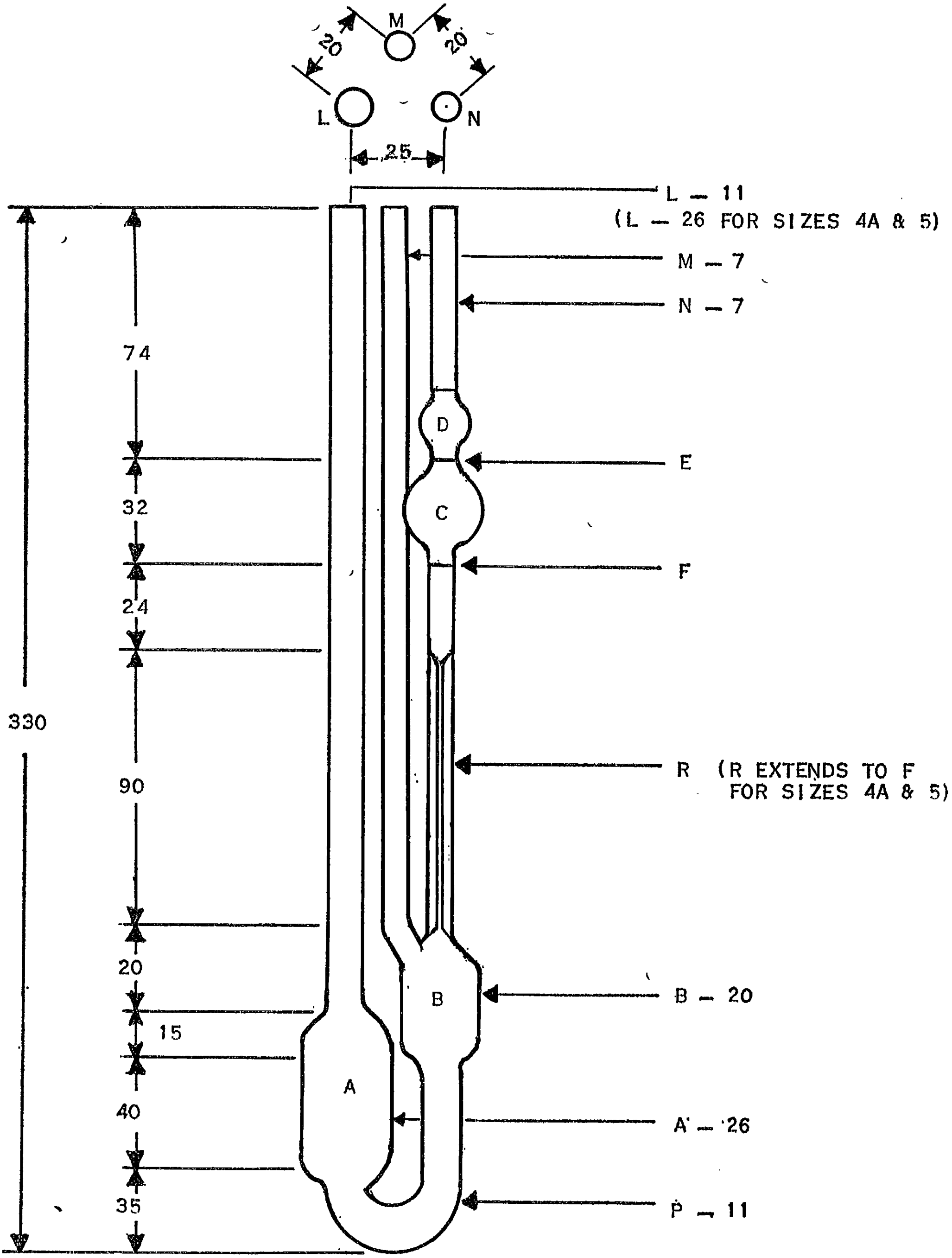
NOTE—All dimensions are in millimeters.

FIG. B2—Fitzsimons Viscometer for Transparent Liquids.



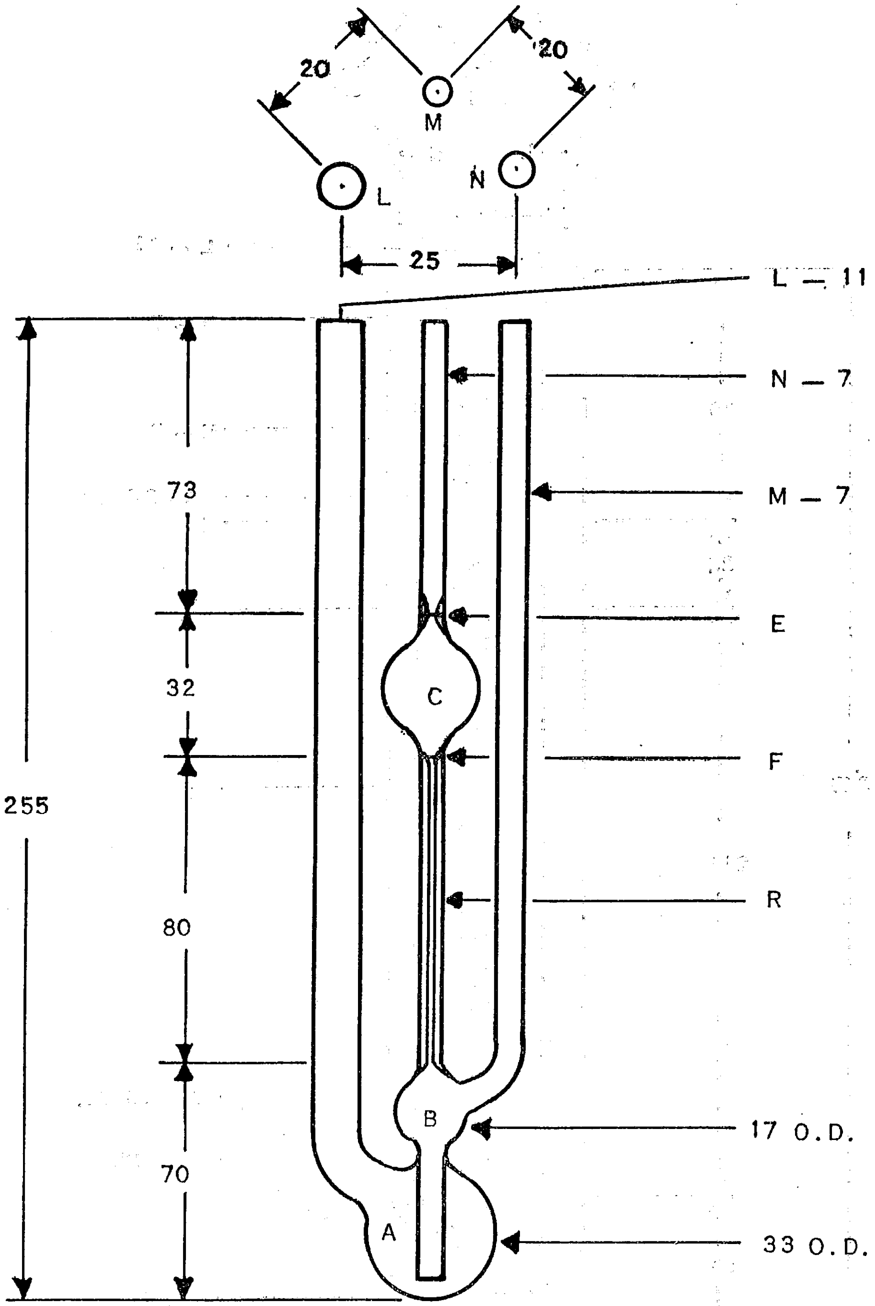
NOTE—All dimensions are in millimeters.

FIG. B3—Atlantic Viscometer for Transparent Liquids.



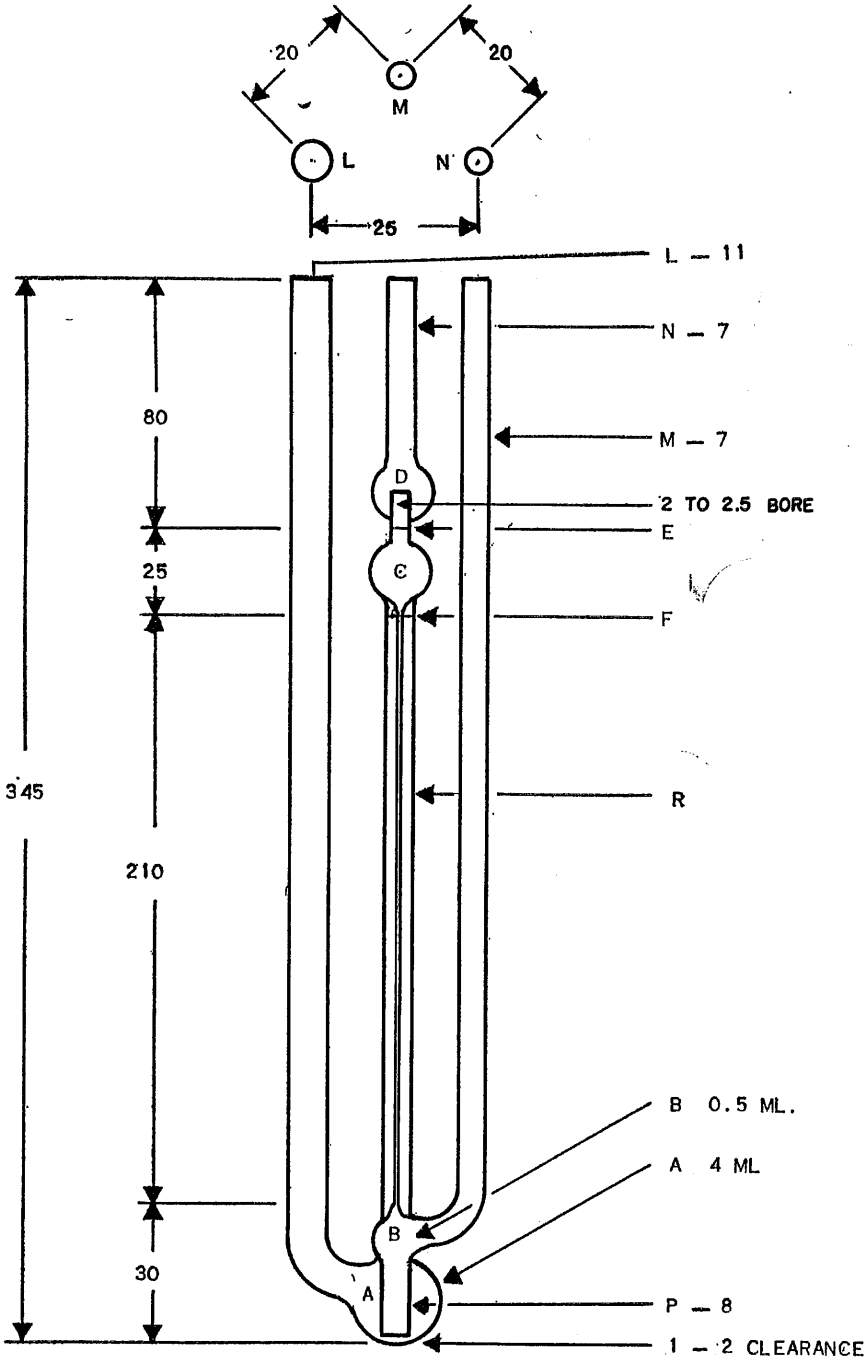
NOTE—All dimensions are in millimeters.

FIG. B4—BS/IP/SL Viscometer for Transparent Liquids.



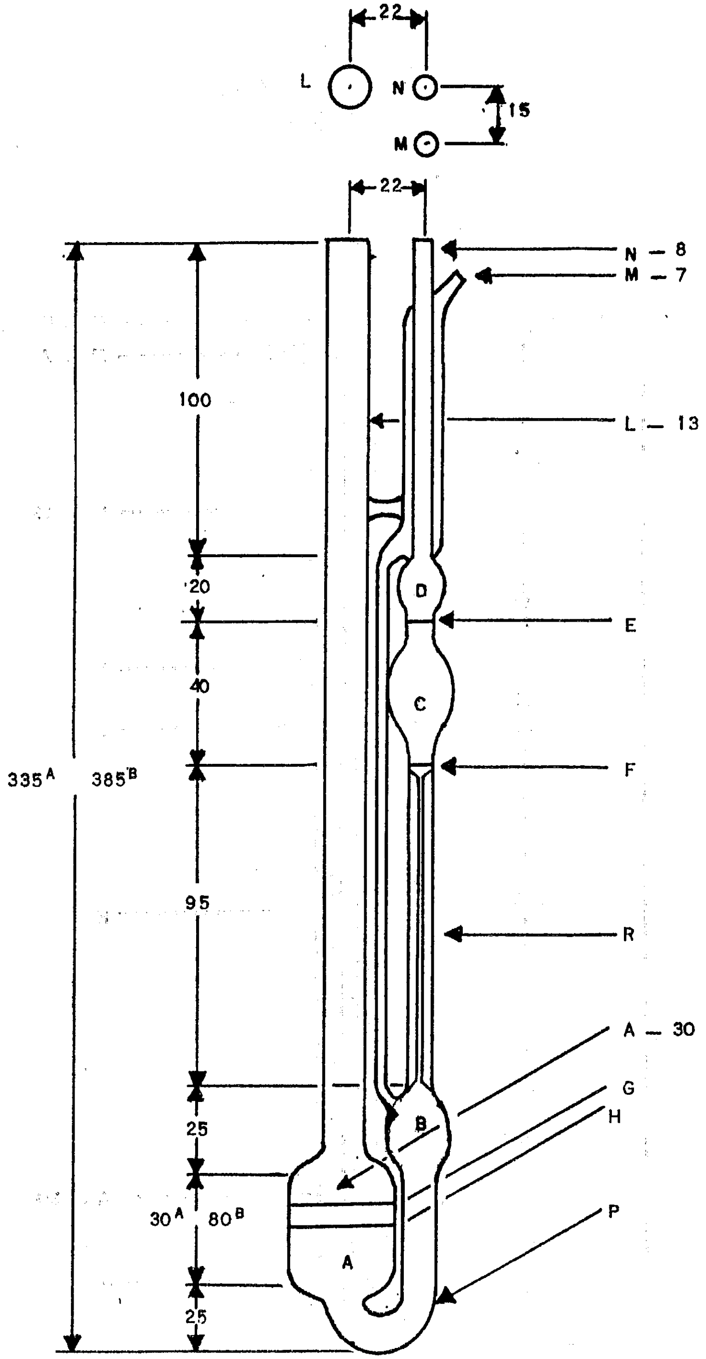
NOTE—All dimensions are in millimeters.

FIG. B5—BS/IP/SL(S) Viscometer for Transparent Liquids.



NOTE—All dimensions are in millimeters.

FIG. B6—BS/IP/MSL Viscometer for Transparent Liquids.



NOTE—All dimensions are in millimeters.

FIG. B7—Cannon-Ubbelohde (A) and Cannon-Ubbelohde Dilution (B) Viscometer for Transparent liquids.

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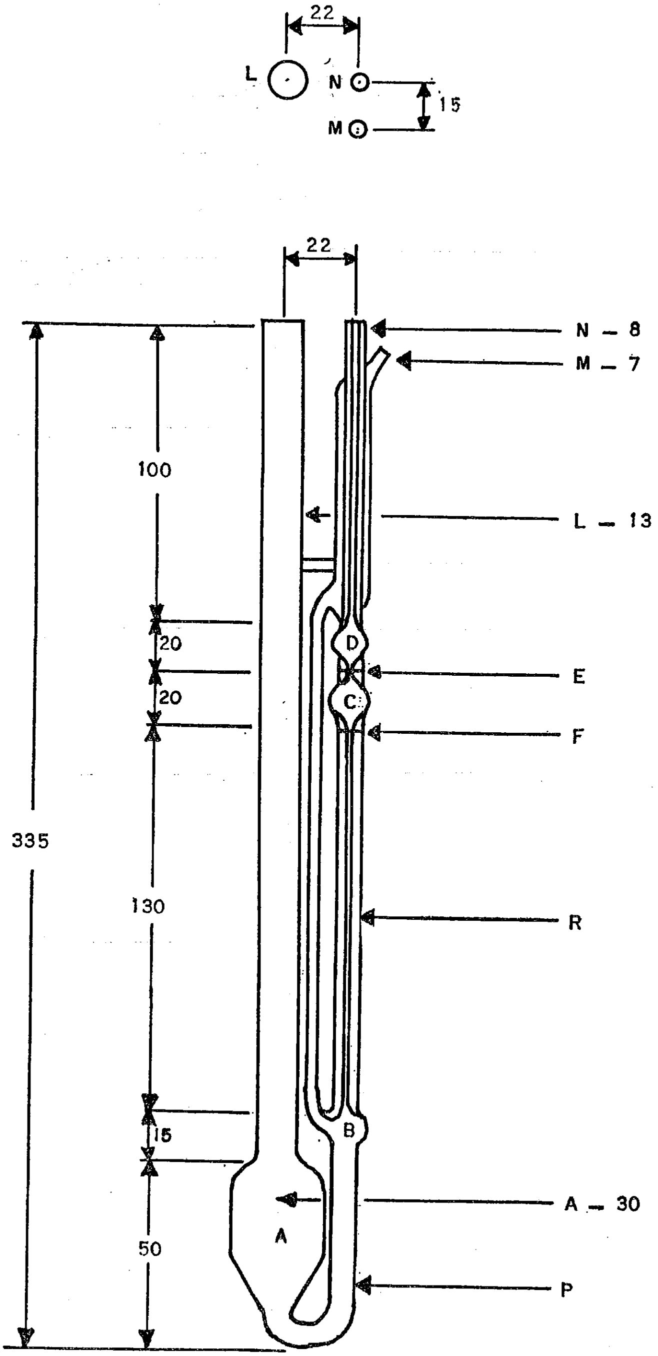


NOTE—All dimensions are in millimeters.

FIG. B8—Cannon-Ubbelohde Semi-Micro Viscometer for Transparent Liquids.

TABLE B1—DIMENSIONS AND VISCOSITY RANGES FOR THE UBBELOHDE VISCOMETER.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Volume, Bulb *C*, ml (±5 per cent)	Inside Diameter of Tube *P*, ml (±5 per cent)
0	0.001	0.3[a] to 1	0.24	1.0	6.0
0C	0.003	0.6 to 3	0.36	2.0	6.0
0B	0.005	1 to 5	0.46	3.0	6.0
1	0.01	2 to 10	0.58	4.0	6.0
1C	0.03	6 to 30	0.78	4.0	6.0
1B	0.05	10 to 50	0.88	4.0	6.0
2	0.1	20 to 100	1.03	4.0	6.0
2C	0.3	60 to 300	1.36	4.0	6.0
2B	0.5	100 to 500	1.55	4.0	6.0
3	1.0	200 to 1 000	1.83	4.0	6.0
3C	3.0	600 to 3 000	2.43	4.0	6.0
3B	5.0	1 000 to 5 000	2.75	4.0	6.5
4	10	2 000 to 10 000	3.27	4.0	7.0
4C	30	6 000 to 30 000	4.32	4.0	8.0
4B	50	10 000 to 50 000	5.20	5.0	8.5
5	100	20 000 to 100 000	6.25	5.0	10.0

[a] 300 sec minimum flow time.

TABLE B2—DIMENSIONS AND VISCOSITY RANGES FOR THE FITZSIMONS VISCOMETER.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Volume, Bulb C, ml (±5 per cent)
1	0.003	0.6 to 3.0	0.43	3.0
2	0.01	2 to 10	0.60	3.7
3	0.035	7 to 35	0.81	3.7
4	0.10	20 to 100	1.05	3.7
5	0.25	50 to 250	1.32	3.7
6	1.20	240 to 1200	1.96	3.7

TABLE B3—DIMENSIONS AND VISCOSITY RANGE FOR ATLANTIC VISCOMETERS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Volume, Bulb *C*, ml (±5 per cent)
0C	0.003	0.75[a] to 3	0.42	3.2
0B	0.005	1 to 5	0.46	3.2
1	0.01	2 to 10	0.56	3.2
1C	0.03	6 to 30	0.74	3.2
1B	0.05	10 to 50	0.83	3.2
2	0.1	20 to 100	1.00	3.2
2C	0.3	60 to 300	1.31	3.2
2B	0.5	100 to 500	1.48	3.2
3	1.0	200 to 1000	1.77	3.2
3C	3.0	600 to 3000	2.33	3.2
3B	5.0	1000 to 5000	2.64	3.2

[a] 250 sec minimum flow time.

TABLE B4—DIMENSIONS AND VISCOSITY RANGES FOR BS/IP/SL VISCOMETER FOR TRANSPARENT LIQUIDS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Volume, Bulb *C*, ml (±5 per cent)	Inside Diameter of Tube *N*
1	0.01	3.5[a] to 10	0.64	5.6	2.8 to 3.2
1A	0.03	6 to 30	0.84	5.6	2.8 to 3.2
2	0.1	20 to 100	1.15	5.6	2.8 to 3.2
2A	0.3	60 to 300	1.51	5.6	2.8 to 3.2
3	1.0	200 to 1 000	2.06	5.6	3.7 to 4.3
3A	3.0	600 to 3 000	2.74	5.6	4.6 to 5.4
4	10	2 000 to 10 000	3.70	5.6	4.6 to 5.4
4	30	6 000 to 30 000	4.97	5.6	5.6 to 6.4
5	100	20 000 to 100 000	6.76	5.6	6.8 to 7.5

[a] 350 sec minimum flow time.

TABLE B5—DIMENSIONS AND VISCOSITY RANGES FOR BS/IP/SL(S) VISCOMETER FOR TRANSPARENT LIQUIDS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Volume, Bulb *C*, ml (±5 per cent)	Inside Diameter of Tube *N*, mm	Inside Diameter of Tube at *E*, mm
1	0.0008	1.05[a] min,	0.36	5.6	2.8 to 3.2	3
2	0.003	2.1[b] to 3	0.49	5.6	2.8 to 3.2	3
3	0.01	3.8[c] to 10	0.66	5.6	2.8 to 3.2	3
4	0.03	6 to 30	0.87	5.6	2.8 to 3.2	3
5	0.1	20 to 100	1.18	5.6	2.8 to 3.2	3
6	0.3	60 to 300	1.55	5.6	2.8 to 3.2	3
7	1.0	200 to 1 000	2.10	5.6	3.7 to 4.3	4
8	3.0	600 to 3 000	2.76	5.6	4.6 to 5.4	5
9	10.0	2 000 to 10 000	3.80	5.6	4.6 to 5.4	5

[a] 1320 sec minimum flow time.
[b] 690 sec minimum flow time.
[c] 380 sec minimum flow time.

TABLE B6—DIMENSIONS AND VISCOSITY RANGES FOR BS/IP/MSL VISCOMETER FOR TRANSPARENT LIQUIDS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Volume, Bulb *C*, ml (±5 per cent)	Inside Diameter of Tubes *N* and *P*
1	0.003	0.6 to 3	0.35	1.2	4 to 6
2	0.01	2 to 10	0.45	1.2	4 to 6
3	0.03	6 to 30	0.62	1.2	4 to 6
4	0.1	20 to 100	0.81	1.2	4 to 6
5	0.3	60 to 300	1.10	1.2	4 to 6
6	1.0	200 to 1000	1.45	1.2	4 to 6
7	3.0	600 to 3000	1.98	1.2	4 to 6

if the sample contains volatile constitutes) to draw the sample slowly through bulb *C* to about 8 mm above upper timing mark *E*. Release vacuum from tube *N* and immediately place finger from tube *M* to tube *N* holding the meniscus above timing mark *E* until the lower meniscus has dropped below the end of capillary *R* in bulb *B*. Release finger and allow the sample to flow by gravity.

TABLE B7—DIMENSIONS AND VISCOSITY RANGES FOR CANNON-UBBELOHDE AND CANNON-UBBELOHDE DILUTION VISCOMETERS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Volume, Bulb *C*, ml (±5 per cent)
25	0.002	0.5^a to 2	0.31	1.5
50	0.004	0.8 to 4.0	0.44	3.0
75	0.008	1.6 to 8.0	0.54	3.0
100	0.015	3 to 15	0.63	3.0
150	0.035	7 to 35	0.78	3.0
200	0.1	20 to 100	1.01	3.0
300	0.25	50 to 250	1.26	3.0
350	0.5	100 to 500	1.48	3.0
400	1.2	240 to 1 200	1.88	3.0
450	2.5	500 to 2 500	2.25	3.0
500	8	1 600 to 8 000	3.00	3.0
600	20	4 000 to 20 000	3.75	3.0
650	45	9 000 to 45 000	4.60	3.0
700	100	20 000 to 100 000	5.60	3.0

[a] 250 sec minimum flow time.

TABLE B8—DIMENSIONS AND VISCOSITY RANGES FOR CANNON-UBBELOHDE SEMI-MICRO VISCOMETERS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Volume, Bulb *C*, ml (±5 per cent)	Inside Diameter of Tubes *N*, *E*, *F*, and *P*, mm
25	0.002	0.4 to 1.0	0.22	0.30	1.2 to 1.4
50	0.004	0.8 to 4	0.25	0.30	1.2 to 1.4
75	0.008	1.6 to 8	0.30	0.30	1.2 to 1.4
100	0.015	3 to 15	0.36	0.30	1.2 to 1.4
150	0.035	7 to 35	0.47	0.30	1.2 to 1.4
200	0.1	20 to 100	0.61	0.30	1.4 to 1.7
300	0.25	50 to 250	0.76	0.30	1.5 to 1.8
350	0.5	100 to 500	0.90	0.30	1.8 to 2.2
400	1.2	240 to 1 200	1.13	0.30	2.1 to 2.5
450	2.5	500 to 2 500	1.40	0.30	2.4 to 2.8
500	8	1 600 to 8 000	1.85	0.30	2.7 to 3.1
600	20	4 000 to 20 000	2.35	0.30	3.7 to 4.0

(*e*) Measure to the nearest 0.1 sec the time required for the leading edge of the meniscus to pass from timing mark *E* to timing mark *F*. If the flow time is less than 200 sec, select a smaller capillary viscometer and repeat steps (*b*) through (*e*).

(*f*) Repeat steps (*d*) and (*e*) making a duplicate measurement of flow time. If the two measurements agree within 0.2 per cent, use the average for calculating kinematic viscosity.

(*g*) Clean the viscometer thoroughly by several rinsings with an appropriate solvent completely miscible with the sample, followed by rinsing with a completely volatile solvent. Dry the viscometer by passing a slow stream of filtered, dry air through the viscometer for 2 min, or until the last trace of solvent is removed.

REFERENCES

(1) L. Ubbelohde, "The Suspended Level Viscometer," *Journal*, Institute of Petroleum Technology (London), Vol. 22, 1936, p. 37.

(2) O. FitzSimons, "A Rapid Precision Viscometer," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 7, 1935, p. 345.

(3) J. J. Watt and C. E. Headington, "New Viscometer Solves Old Problems," *Petroleum Refiner*, October 1954.

(4) M. R. Cannon and R. E. Manning, "Viscosity Measurement," *Analytical Chemistry*, Vol. 32, 1960, p . 355.

APPENDIX C

REVERSE-FLOW VISCOMETERS

Scope

C1. The reverse-flow viscometers for transparent and opaque liquids include the Cannon-Fenske Opaque, Zeitfuchs Cross-Arm, BS/IP/RF, and Lantz- Zeitfuchs viscometers. Unlike the modified Ostwald and suspended-level viscometers, the sample of liquid flows into a timing bulb not previously wet by sample, thus allowing the timing of liquids whose thin films are opaque. Reverse-flow viscometers are used for the measurement of kinematic viscosities of opaque and transparent liquids up to 100,000 cSt.

Apparatus

C2. Detailed drawings of the reverse-flow viscometers are shown in Figs. C1 through C4. Tables C1 through C4 give the size designations, approximate constant, kinematic viscosity range, capillary diameter, and bulb volumes for each viscometer.

Operating Instructions

C3. A standard operating procedure applicable to all glass capillary, kinematic viscometers is contained in Method D 445. Operating instructions for the reverse-flow viscometers are outlined in Paragraphs (*a*) through (*g*) with emphasis on procedures that are specific to a particular instrument or this group of instruments.

(*a*) Select a clean, dry viscometer which will give a flow time greater than 200 sec and a kinetic energy correction of less than 0.2 per cent.

(*b*) Charge the viscometer in the manner dictated by the design of the instrument, this operation being in conformity with that employed when the instrument was calibrated. If the sample may contain lint, solid particles, etc., filter as prescribed in Method D 445.

(*1*) To charge the Cannon-Fenske Opaque viscometer, invert the viscometer and apply suction to the tube *L*, immersing tube *N* in the liquid sample. Draw liquid through tube *N*, filling bulb *D* to fill mark *G*. Wipe excess sample off tube *N* and invert the viscometer to its normal position. Mount the viscometer in the constant-temperature bath, keeping tube *I* vertical.

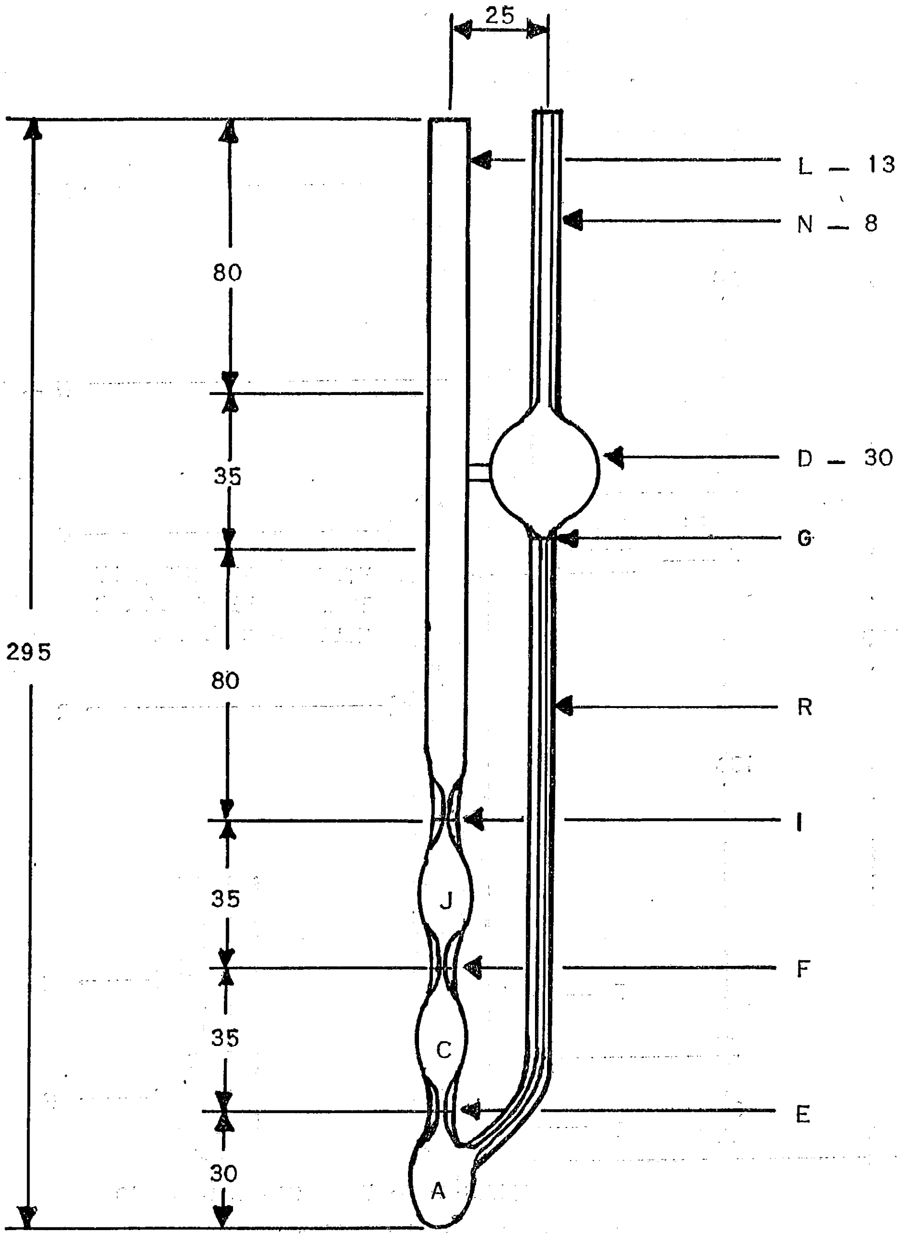
(*2*) Mount the Zeitfuchs Cross-Arm viscometer in the constant-temperature bath, keeping tube *N* vertical. Introduce sample through tube *N* taking care not to wet the sides of tube *N*, into the cross-arm *D* until the leading edge stands within 0.5 mm of fill mark *G* on the siphon tube.

(*3*) Mount the Lantz-Zeitfuchs viscometer in the constant-temperature bath keeping tube *N* vertical. Introduce sufficient sample through tube *N* to completely fill bulb *D*, overflowing slightly into overflow bulb *K*. If the sample is poured at a temperature above test temperature, wait 15 min for the sample in the viscometer to attain bath temperature and add more sample to overflow slightly into bulb *K*.

(*4*) Mount the BS/IP/RF viscometer in the constant-temperature bath keeping tube *L* vertical. Pour sample through tube *N* to a point just above filling mark *G;* allow the sample to flow freely through capillary *R*, taking care that the liquid column remains unbroken, until the lower meniscus is about 5 mm below the filling mark *H* and then arrest its flow by closing the timing tube with a cork or rubber stopper in tube *L*. Add more liquid if necessary to bring the upper meniscus slightly above mark *G*. After allowing the sample to attain bath temperature (see Paragraph (*c*)) and any air bubbles to rise to the surface, gently loosen the stopper allowing the sample to flow to the lower filling mark *H* and again arrest flow. Remove the excess sample above filling mark *G* by inserting the special pipet until its cork rests on top of tube *N;* apply gentle suction until air is drawn through. The upper meniscus shall coincide with mark *G*.

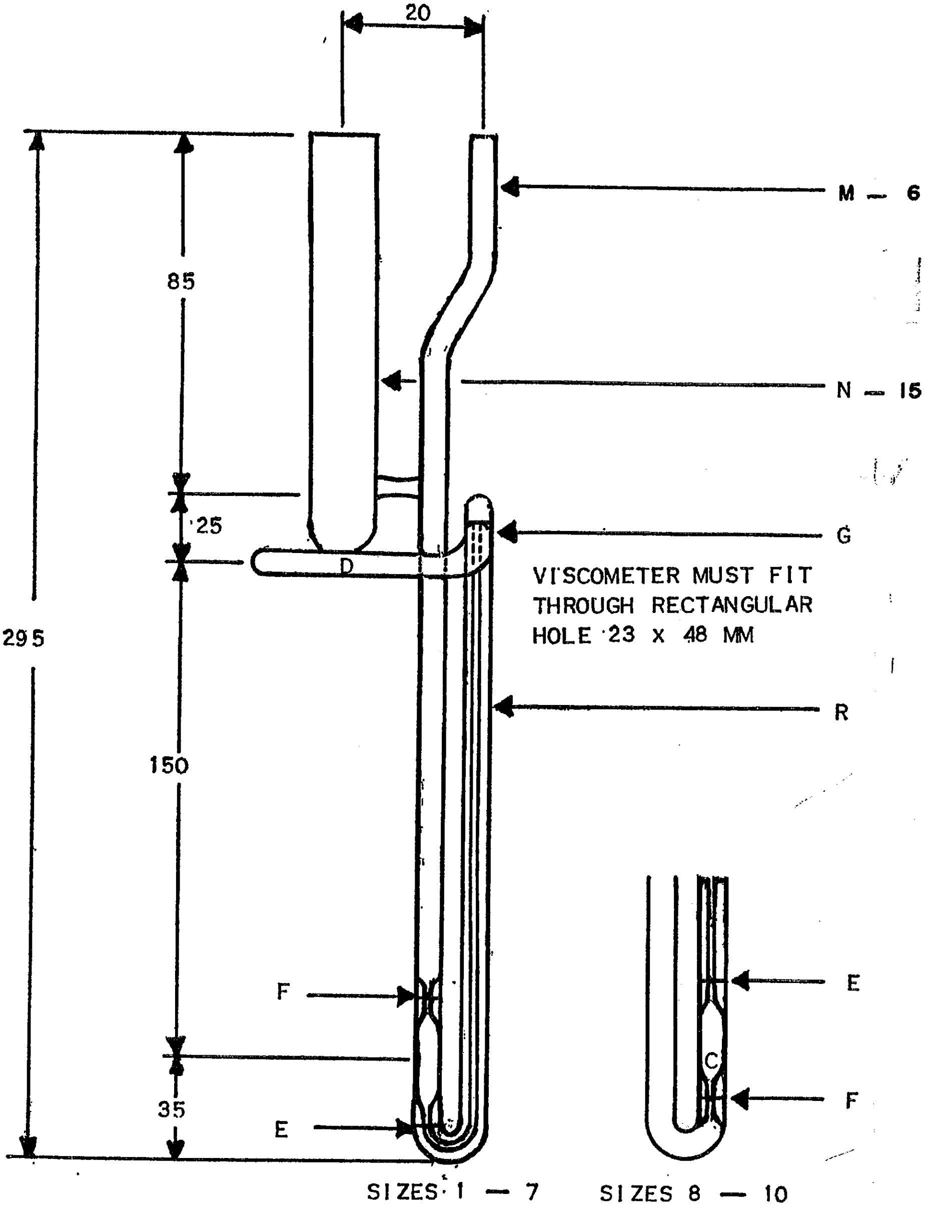
(*c*) Allow the viscometer to remain in the constant-temperature bath a sufficient time to ensure that the sample reaches temperature equilibrium (about 20 min at 100 F, 25 min at 210 F, and 30 min at 275 F).

(*d*) For the Cannon-Fenske Opaque and BS/IP/RF viscometers, remove the stopper in tubes *N* and *L*, respectively, and allow the sample to flow by gravity. For the Zeitfuchs



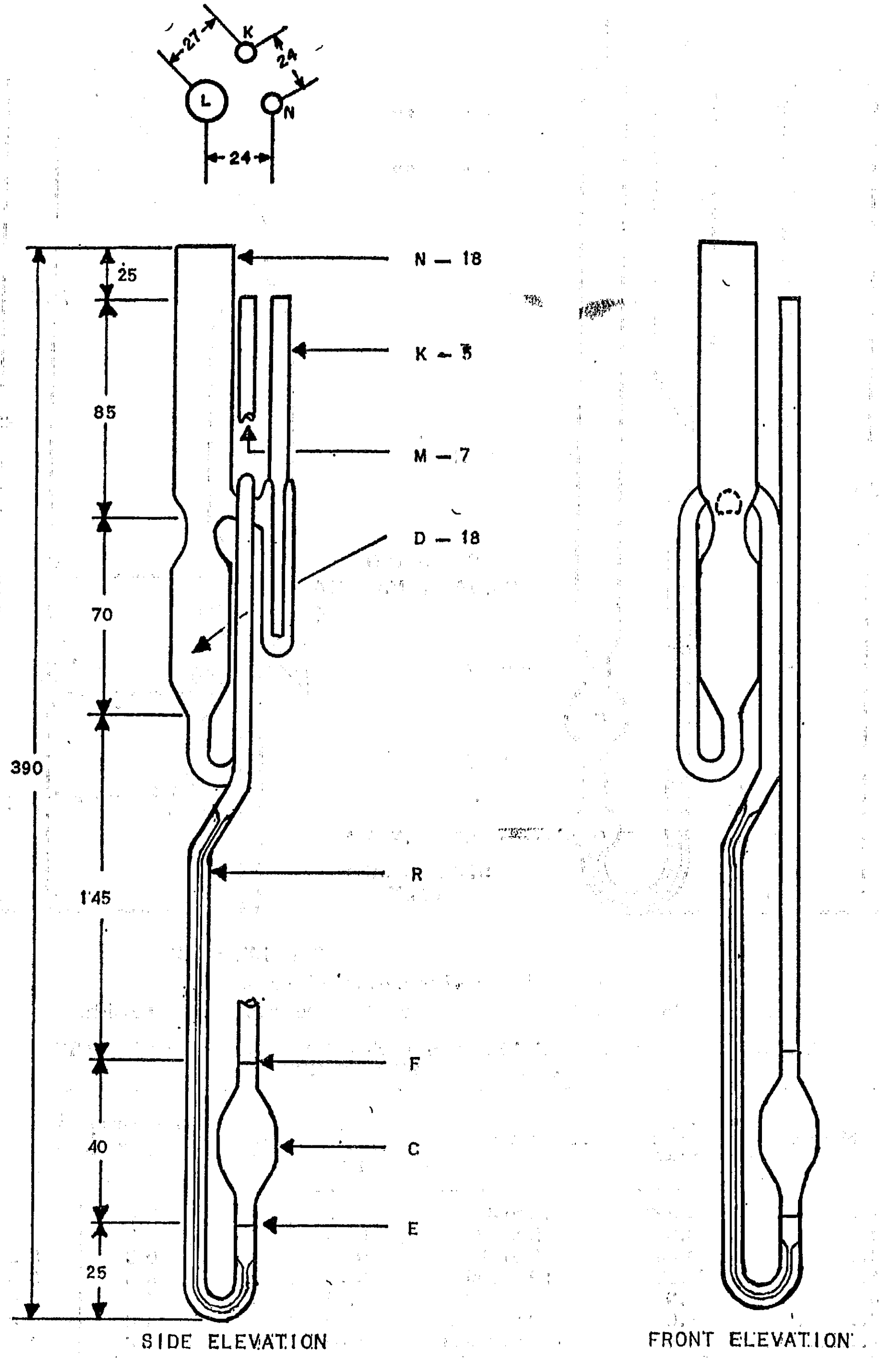
NOTE—All dimensions are in millimeters.

FIG. C1—Cannon-Fenske Opaque Viscometer for Opaque and Transparent Liquids.



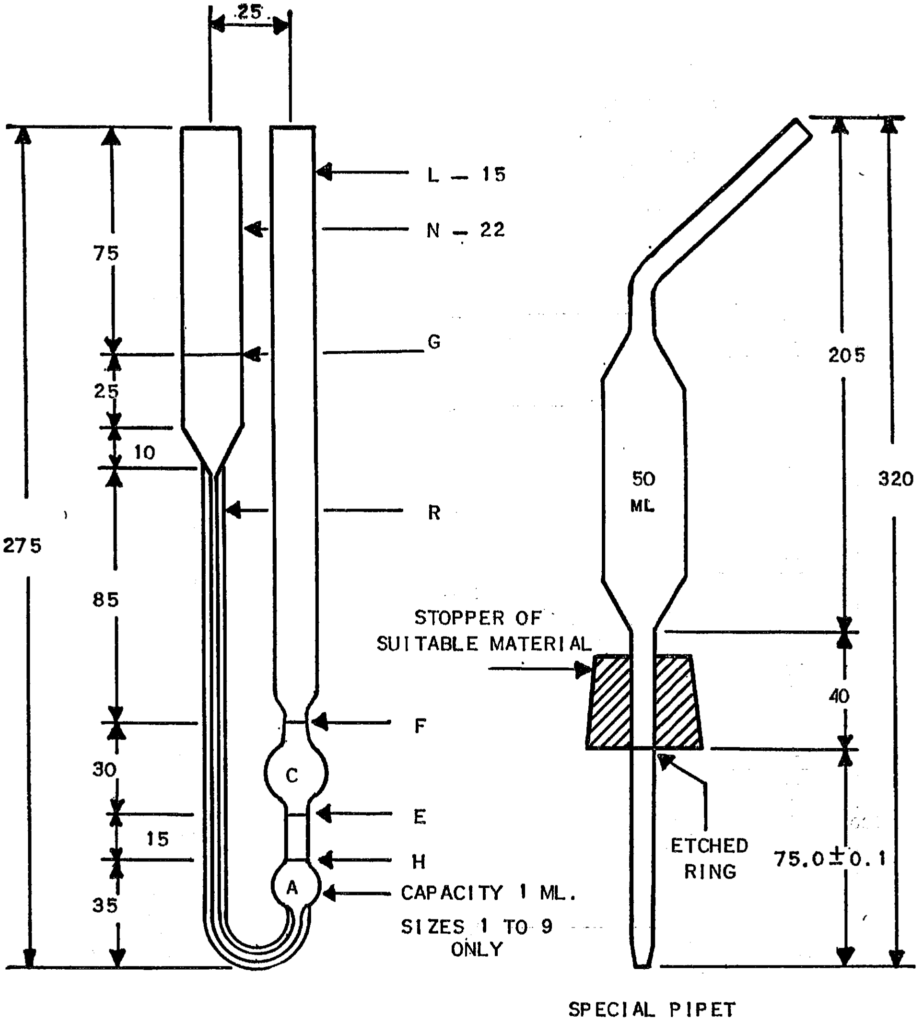
NOTE—All dimensions are in millimeters.

FIG. C2—Zeitfuchs Cross-Arm Viscometer for Transparent and Opaque Liquids.



NOTE—All dimensions are in millimeters.

FIG. C3—Lantz-Zeitfuchs Type Reverse Flow Viscometer for Opaque Liquids.



NOTE—All dimensions are in millimeters.

FIG. C4—BS/IP/RF U-Tube Reverse Flow Viscometer for Opaque Liquids.

TABLE C1—DIMENSIONS AND VISCOSITY RANGES FOR ZEITFUCHS CROSS-ARM VISCOMETERS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Length of Tube *R*, mm	Lower Bulb Volume, ml (±5 per cent)	Horizontal Tube Diameter, mm (±5 per cent)
1...........	0.003	0.6 to 3	0.27	210	0.3	3.9
2...........	0.01	2 to 10	0.35	210	0.3	3.9
3...........	0.03	6 to 30	0.46	210	0.3	3.9
4...........	0.10	20 to 100	0.64	210	0.3	3.9
5...........	0.3	60 to 300	0.84	210	0.3	3.9
6...........	1.0	200 to 1 000	1.15	210	0.3	4.3
7...........	3.0	600 to 3 000	1.42	210	0.3	4.3
8...........	10.0	2 000 to 10 000	1.93	165	0.25	4.3
9...........	30.0	6 000 to 30 000	2.52	165	0.25	4.3
10...........	100.0	20 000 to 100 000	3.06	165	0.25	4.3

TABLE C2—DIMENSIONS AND VISCOSITY RANGES FOR CANNON-FENSKE OPAQUE VISCOMETERS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Inside Diameter of Tube *N* and G Tubes *E*, *F*, and *I*, mm (±5 per cent)	Volume Bulbs *A*, *C*, and *J*, ml (±5 per cent)	Volume, Bulb *D*, ml (±5 per cent
25........	0.002	0.4 to 2	0.31	3.0	1.6	11
50........	0.004	0.8 to 4	0.42	3.0	2.1	11
75........	0.008	1.6 to 8	0.54	3.0	2.1	11
100........	0.015	3 to 15	0.63	3.2	2.1	11
150........	0.035	7 to 35	0.78	3.2	2.1	11
200........	0.1	20 to 100	1.02	3.2	2.1	11
300........	0.25	50 to 200	1.26	3.4	2.1	11
350........	0.5	100 to 500	1.48	3.4	2.1	11
400........	1.2	240 to 1 200	1.88	3.4	2.1	11
450........	2.5	500 to 2 500	2.20	3.7	2.1	11
500........	8	1 600 to 8 000	3.10	4.0	2.1	11
600........	20	4 000 to 20 000	4.00	4.7	2.1	13

TABLE C3—DIMENSIONS AND VISCOSITY RANGES FOR LANTZ-ZEITFUCHS VISCOMETERS.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Length of Tube *R*, mm	Volume, Bulb *C*, ml (±5 per cent)
5..........	0.3	60 to 300	1.65	490	2.7
6..........	1.0	200 to 1 000	2.25	490	2.7
7..........	3.0	600 to 3 000	3.00	490	2.7
8..........	10.0	2 000 to 10 000	4.10	490	2.7
9..........	30.0	6 000 to 30 000	5.20	490	2.7
10..........	100.0	20 000 to 100 000	5.20	490	0.85

TABLE C4—DIMENSIONS AND VISCOSITY RANGES FOR BS/IP/RF VISCOMETER.

Size No.	Approximate Constant, cSt/sec	Viscosity Range, cSt	Inside Diameter of Tube *R*, mm (±2 per cent)	Length of Tube *R*, mm	Inside Diameter at *E*, *F* , and *G*, mm	Volume Bulb *C*, ml (±5 per cent)
1.......	0.003	0.6 to 3	0.51	185	3.0 to 3.3	4.0
2.......	0.01	2 to 10	0.71	185	3.0 to 3.3	4.0
3.......	0.03	6 to 30	0.93	185	3.0 to 3.3	4.0
4.......	0.1	20 to 100	1.26	185	3.0 to 3.3	4.0
5.......	0.3	60 to 300	1.64	185	3.0 to 3.3	4.0
6.......	1.0	200 to 1 000	2.24	185	3.0 to 3.3	4.0
7.......	3.0	600 to 3 000	2.93	185	3.3 to 3.6	4.0
8.......	10	2 000 to 10 000	4.00	185	4.4 to 4.8	4.0
9.......	30	6 000 to 30 000	5.5	185	6.0 to 6.7	4.0
10.......	100	20 000 to 100 000	7.70	210	7.70	4.0
11.......	300	60 000 to 300 000	10.00	210	10.00	4.0

Cross-Arm viscometer, apply slight vacuum to tube *N* (or pressure to tube *L*) to cause the meniscus to move over the siphon tube and about 30 mm below the level of tube *D* in capillary *R;* gravity flow is thus initiated. For the Lantz-Zeitfuchs viscometer, apply slight vacuum to tube *M* (or pressure to tube *N* with tube *K* closed) until the lower meniscus is opposite the lower timing mark *E;* allow the sample to flow by gravity.

(*e*) Measure to the nearest 0.1 sec the time required for the leading edge of the meniscus to pass from timing mark *E* to timing mark *F*. If the flow time is less than 200 sec, select a smaller capillary viscometer and repeat steps (*b*) through (*e*).

(*f*) Using this viscometer or a second viscometer, repeat steps (*b*) through (*e*) making a duplicate determination of viscosity. Calculate the viscosity. If the two determinations differ by less than 0.35 per cent, report the average of the calculated viscosities.

(*g*) Clean the viscometer thoroughly by several rinsings with an appropriate solvent completely miscible with the sample, followed by a completely volatile solvent. Dry the viscometer by passing a slow stream of filtered, dry air through the viscometer for 2 min, or until the last trace of solvent is removed.

REFERENCES

(1) M. R. Cannon and M. R. Fenske, "Viscosity Measurement—Opaque Liquids," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 13, p. 299, 1941.

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